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VAPOR-LIQUID PHASE SEPAPATOR STUDIES

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S.W.K.Yuan
W.A.Hepler
T.H.K.Frederking

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VAPOR-LIQUID PHASE SEPARATOR STUDIES

S.W.K.Yuan
W.A.Hepler
T.H.K.Frederking
School of Engineering and Applied Science
University of California at Los Angeles
Los Angeles, CA 90024

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CONTENTS

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1. General Summary

Vapor-liquid phase separation by means of porous plugs ("Fairbank plugs") has been explored since the Seventies in preparation for flight demonstration. The latter has been initiated in 1983. This year provided data of the IRAS system. The results include actual performance data of porous plugs in space acting as important subsystem components for the cryogenic liquid.

NASA Grant NCC 2-64 in particular had the purpose of providing answers in three main areas related to porous plug use for phase separation. These points are expressed as three main questions:

1. Are porous media useful even when design specifications call for variable areas and flow rates respectively ? ;

2. Is it possible to predict <u>main</u> parameters of porous plugs for a particular material selected ? ;

3. Is it possible to predict <u>all</u> parameters of the plugs including secondary ones ? .

Area 1 is also referred to as flow modulation R & D work based on porous media, and this question has been answered by a particular demonstration of a device using a stainless steel plug. This work is described in the CEC paper listed in Section 2.

Area 2 is in between the simple packed bed system of spheres and the complex situation delineated as area 3. The latter has been found to be quite complicated. Thus, partial progress has been achieved related primarily to questions of area 2. In particular, there has been a lengthy search for characteristic lengths determining the throughput. This effort led to the proposal to employ a single characteristic length L_c which is the square root of the permeability of the plug. The results obtained, listed in Section 2, so far show that indeed L_c is a very useful parameter. Throughput-pressure drop functions are conveniently combined in dimensionless form. The dimensionless groups studied include L_c. Starting from

Stokes - Darcy solutions it has been possible to place upper bounds on the functional range of transport covered by porous plug phase separators. The studies have been complex because of the use of different sets of parameters by plug manufacturers. The latter deal primarily with solid-fluid separation, and the characterization efforts are directed toward information about the solids to be filtered out.

Concerning material selection it is noted that stainless steel has been preferred . However , the use of a lubricant during pre-sintering operations introduces more complicated conditions than in near-spherical particle beds . Examples of the latter are known from basic studies, and bronze plugs and tungsten plugs have been found to be relatively close to packed beds of near-spherical particles. In particular, experiments have been run on the smallest bronze plug commercially available . It turns out that the zero net mass flow mode constitutes an asymptote to the phase separation mode when the temperature is lowered.

Concerning area 3 , the studies so far have indicated that there exist secondary parameters for each type of plug. They are modifying the length L_c,to some extent,along with the flow characteristics of laminar and turbulent flow. Thus, a basic frame of reference has been achieved up to this point, and more detailed work concerning the usefulness of the frame for different classes of plugs appears to be the next step.

Details of the work carried out are listed in the subsequent bibliographical data sections.

2. BIBLIOGRAPHICAL REFERENCES *

a. Paper Presentations at Conferences

"Sintered Plug Flow Modulation of a Vapor-Liquid Phase Separator For a Helium II Vessel ", T.H.K. Frederking, C. Chuang, Y. Kamioka, J.M. Lee and S.W.K. Yuan , Paper CB-3 , presented at Cryogenic Engng. Conference, Colorado Springs, Aug. 1983;

"Plug Flow Comparison", S.W.K. Yuan, J.M. Lee and T.H.K. Frederking, Paper presented at Space Helium Dewar Conference and Workshop, sponsored by NASA, Marshall Space Flight Center and Organized by the University of Alabama in Huntsville, Alabama 35899 ;

b. Publications

"Sintered Plug Flow Modulation of a Vapor-Liquid Phase Separator for a Helium II Vessel" , T.H.K. Frederking, C. Chuang, Y. Kamioka, J.M. Lee and S.W.K. Yuan, accepted for publication in Volume 29, Advances in Cryogenic Engineering, (expected to be published in 1984).

"Plug Flow Comparison" , listed under (a) is expected to be published by the organizers in 1984.

c. Thesis Work

Sidney W. Yuan, The Characterization of Sintered Stainless Steel Porous Plugs for Vapor-Liquid Phase Separation of He II , M. Sc. thesis, University of California , Los Angeles 1981 .

Jeffrey Marshall Lee, Permeabilities of Sintered Porous Metal Plugs and Transport Rates of Vapor-Liquid Phase Separators for Helium II Vessels, M. Sc. thesis, University of California, Los Angeles 1983.

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*) Additional work related in part to these topics is compiled in Section 3.

3. ADDITIONAL REFERENCES RELATED IN PART TO NASA GRANT NCC 2-64

There has been preceding work on porous plugs listed below. In addition, an NSF Grant has been concerned with thermo-osmotic transport phenomena. In general, porous plugs will be subject to thermal boundary conditions of a non-adiabatic nature (diathermal/ diathermic boundaries with finite heat transfer rates). This point has been made by U. Schotte (Physica 107B, 1981,577-578) for wall effects of non-isothermal pin devices used for phase separation. In addition there may be transient effects. Thus, there may be an <u>indirect</u> relation to solid- He II interaction , in particular during accidental anomalies of system operation. The flow modulator listed in Section 2 incorporates a rotatable shutter. There has been a previous phase of rotating He^4 research (supported by an NSF Grant). In line with these additional topics, papers in those categories are listed below.

3a. Preceding work

"Vapor-Liquid Phase Separation of Cryogenic Liquid Storage Systems Below the Lambda Point (He^4), C. Chuang, Y.I. Kim and T.H.K. Frederking, Cryog. Proc. Equipment, ASME Publ. No. H00164, pp. 135-140, 1980.

3b. Thermo-Osmotic Transport Phenomena

"Darcy Law of Thermo-Osmosis for Zero Net Mass Flow at Low Temperatures", S.W.K. Yuan and T.H.K. Frederking, Proc. ASME-JSME Joint Thermal Engng. Conf., Honolulu, March 1983, Vol.2, pp. 191-197 (1983).

3c. Thermal Boundary Conditions Including Transients

"Transient Triple-Phase Transitions in Superfluid Liquid Helium II, C. Chuang, Y. Kamioka and T.H.K. Frederking, Adv. Cryog. Engng. 27, 1982,pp. 493-500.

3c. Thermal Boundary Conditions (contin.)

"Formvar Coating Effects on Heat Transfer from NbTi/Cu to Liquid Helium: Dynamic Evaluation of the Formvar Thermal Conductivity, L.H. Lin, C. Chuang and T.H.K. Frederking, ICEC-9, Proc. 9th Int. Cryogenic Eng. Conf., Kobe, pp. 57-60, 1982.

"Influence of the Kapitza Resistance on Nucleate Boiling of Liquid Helium" L.H. Lin and T.H.K. Frederking, Letters in Heat and Mass Transfer 9, pp. 473-478, 1982.

"Transient Superconductor (NbTi/Cu)- He II Heat Transfer Rates to Pressurized Superfluid During Step Input in Power, C. Chuang, Y. Kamioka and T.H.K. Frederking, Refrigeration Science and Technology, Int. Inst. Refrig., Vol. 1981-6,pp. 63-68, 1981.

"Quenches of Formvar-Coated NbTi/Cu Caused by Step Input in Power", L.H. Lin, C. Chuang, Y.I. Kim and T.H.K. Frederking, IEEE Trans. Magnetics , Vol. MAG-19, pp. 212 - 215, 1983.

3d. Rotating Helium at Low Temperatures

"Axial Transfer Tube Heat Leak of Rotating Superconducting Machines: Fluid Contribution, Y.I. Kim, C. Chuang and T.H.K. Frederking, IEEE Trans. Magnetics, Vol. MAG-17, pp. [illegible]0 - 133, 1981.

"Irreversible Thermodynamics of Cryo-Fluid Convection (Newtonian Fluid Convection), Y.I. Kim and T.H.K. Frederking, AIChE Symposium Series No. 224, Vol. 79, pp. 114 -119, 1983.

3e. He II Convection

"Influence of Forced Flow on the He II - He I Transition in the Presence of Heat Flow", S. Caspi and T.H.K. Frederking, J. Heat Transfer, Vol. 105, pp.846 - 850, 1983.

ABSTRACT OF THESIS

The Characterization of Sintered Stainless Steel Porous Plugs for Vapor-Liquid Phase Separation of He II

by

Sidney W. Yuan

Master of Science in Engineering

University of California, Los Angeles, 1981

Professor Traugott H. K. Frederking, Chairman

The vapor-liquid phase separation of He II by means of porous plugs has been of great importance in long-term storage of cryogenic liquid for space equipments. It is the purpose of this work to study the properties of sintered stainless steel porous plug with a nominal pore size of 2 μm. The permeability (K_p) at various temperatures was measured by passing He^4 gas through the porous plug at room temperature, liquid nitrogen temperature and liquid helium temperature. In agreement with Darcy's law K_p was found to be 5.65 X 10^{-9} cm^2 at room temperature and K_p = 4.9 X 10^{-9} cm^2 at 77.4 K. The decrease in permeability found experimentally was larger than the contraction rate of bulk stainless steel. Using the assumption that the pores of the plug are made of capillary ducts or slits, a hydraulic radius of 1.33 X 10^{-4} cm was found. In fitting the experimental data by Ergun's equation for packed beds, a particle diameter of 3.3 X 10^{-3} cam was evaluated. The porous plug was further characterized by studying the flow of He II in the plug. The normal fluid permeability $(K_p)_n$ was calculated. It was found that $(K_p)_n$ was lower than the classical permeability. As temperature was lowered, $(K_p)_n$ increased and approached the order of magnitude of the classical value. Thermal circulation convection was found to occur in the porous plug.

ABSTRACT OF THESIS

Permeabilities of Sintered Porous Metal Plugs and Transport Rates of Vapor-Liquid Phase Separators for Helium II Vessels

by

Jeffrey Marshall Lee

Master of Science in Engineering

University of California, Los Angeles, 1983

Professor Traugott H. K. Frederking, Chair

Sintered stainless steel and bronze porous plugs (pore size from 2 to 10 μm) have been characterized for cryogenic liquid-vapor phase separation in dewars, in particular liquid He II vessels. Measured permeabilities (K_p of Darcy's law) of the 2 μm stainless steel plugs show a 10% reduction from 300 K to 77 K with $\bar{K}_p = (5.03 \pm 0.3) \times 10^{-9}$ cm^2 and $\bar{K}_p = (3.2 \pm 0.3) \times 10^{-9}$ cm^2. Plugs of pore size greater than 5 μm show $\bar{K}_p = (3.01 \pm 0.03) \times 10^{-8}$ cm^2 (5 μm stainless steel), and $\bar{K}_p = (1.016 \pm 0.045) \times 10^{-7}$ cm^2 (5 to 15 μm filtration size, bronze).

Data for zero net mass flow through an insulated 2 μm plug in He II agree with a modified Darcy equation of thermo-osmosis based on normal fluid properties, and with related literature values. The viscosity is replaced by the normal fluid viscosity, η_n, and the driving pressure gradient is the thermo-osmotic (thermomechanical) gradient, ∇P_T. The superficial flow speed of normal fluid flow is $\bar{v}_{no} = K_p)_n \nabla P_T/\eta_n$ (superficial heat flux density $\bar{q}_o = \rho ST\bar{v}_{no}$, ($\rho ST$) thermal energy density). At large ∇P_T, $\bar{v}_{no}$-data are below the Darcy value due to turbulence. In the turbulent range, a modified Gorter-Mellink (GM) equation is proposed for $\bar{q}_o$ with an adjustable parameter (K_{GM}). K_{GM} is found to be a monotonically increasing function of the pore size (within the precision of plug definition) for zero net mass flow and phase separation. In addition, a phase separation device with variable cross section has been successfully tested with flow changes of up to ±60% of the mean value.

5. Abstracts of Porous Media Papers

C. Chuang et al. (1980),"Vapor-Liquid Phase Separation.."

In cryo-vessels for space equipment , vapor-liquid phase separation by means of porous plugs has been of interest in several advanced systems (e.g. infrared telescopes). Plug operation is characterized by coupling of the mass throughput to the entropy rejection rate required for controlled vaporization. The latter is accomplished by utilization of the latent heat of vaporization on the vent side. For defined entropy rejection a most useful quantity is the normal fluid flow rate which has to be known for the thermo-osmotic conditions of the plug. Porous media concepts have been applied in a parametric study of various quantities of interest for the flow rate. This approach leads to relatively simple solutions for small transport rates. A comparison of the limited data available with prediction shows partial agreement in the conductance ratio of phase separation expressed as entropy transport ratio.

T.H.K. Frederking et al.(1983)," Sintered Plug Flow Modulation .."

A sintered stainless steel system is described which has the purpose of acting as a vapor-liquid phase separator between a liquid He II bath and the vapor vent line. A variable cross sectional area component is incorporated in order to modulate the mass flow rate through the separator. System details and data are presented.

S.W.K. Yuan et al. (1983)," Plug Flow Comparison".

Flow through porous media including sintered phase separators plugs at low temperatures has been investigated for plugs in the pore size range from 1 to 10 μm. Experiments have been conducted in the liquid Helium II range with 2 μm stainless steel plugs (nominal retention size of filtration). It is proposed to provide a common frame of reference for this type of plugs by means of the modified Darcy flow permeability of normal fluid transport.

5. Abstracts of Porous Plug Papers (contin.)

S.W.K. Yuan et al. (1983), " Darcy Law of Thermo-Osmosis.."

In frequently used solid-fluid material combinations of porous media systems, the thermal conductivity of the solid is significantly larger than the fluid values. In contrast, at low temperatures the solid k-value* may be quite small, and the fluid may reach high k-values locally or over an extended temperature range. In Helium-4 below the lambda temperature (= superfluid He II) thermo-osmotic forces dominate transport phenomena. Darcy transport at low speeds in the laminar range is studied for the material combination of low conductivity solids and He II. The continuum conditions of the two-fluid model are considered. The resulting thermo-osmotic equation does not depend on the superfluid density ratio explicitly. The theoretical results obtained are compared with various data for different types of porous media. Good agreement with prediction is found within uncertainty limits associated with porous media characterization.

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* k thermal conductivity and apparent value associated with convection respectively.

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16. Abstract

Compilation of publications and thesis that resulted from this contract. These references addressed the following questions:

1. Are porous media useful even when design specificaions call for variable areas and flow rates respectively?

2. Is it possible to predict main parameters of porous plugs for a particular material selected?

3. Is it possible to predict all parameters of the plugs including secondary ones?

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